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# Operation UPSHOT-KNOTHOLE

## NEVADA PROVING GROUNDS

March - June 1953

Project 8.11b

IGNITION AND PERSISTENT FIRES
RESULTING FROM ATOMIC EXPLOSIONS—
EXTERIOR KINDLING FUELS




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OPERATION UPSHOT-KNOTHOLE

Project 8.11b

# IGNITION AND PERSISTENT FIRES RESULTING FROM ATOMIC EXPLOSIONS—EXTERIOR KINDLING FUELS

*REPORT TO THE TEST DIRECTOR*

by


Fred M. Sauer, Keith Arnold, W. L. Fons,
and Craig C. Chandler


December 1953

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## ABSTRACT

Probability that mass-fires, fire storms, and conflagrations will occur following atomic attack on urban areas depends on extent and distribution of ignitions as well as fuel, topographic, and weather conditions. Prediction of fire probability is important in military target analysis from both offensive and defensive standpoints. Furthermore, factors which affect this probability are also important to civilian defense planning.

Project 8.11b is part of a research program which is studying extent and distribution of primary ignitions from atomic explosions in urban areas. This project sought to:

1. Determine minimum thermal energies required to ignite those transient exterior kindling fuels found to be dominant by survey of six large representative cities.
2. Study blast effects on persistence of ignition of these fuels.
3. Obtain preliminary information on build-up and spread of primary fires, and provide photographic stock-footage demonstration material of the ignition of heavy combustible structures by transient exterior fuels.

Previous studies have shown that although solid wood surfaces and other common building materials are not ignited by thermal radiation beyond the range of complete blast damage, thin materials like leaves, paper, and rotted wood are ignited by energies in the order of 4 cal/sq cm. Surveys have determined the kinds and distribution of these kindling fuels in urban areas.

For ignition studies prepared trays of transient kindling fuels were exposed to total energies varying from 2.3 to 29.5 cal/sq cm. Car seats, car seat displays, and six groups of three automobiles each were exposed over a thermal range of 6.3 to 29.5 cal/sq cm to study ignition of seat covering materials.

In order to study fire build-up in automobile groups under extreme fire hazard condition a compact group of 13 cars was exposed to 12.2 cal/sq cm. Each car in this group had its seat material ripped in order to expose cotton stuffing material to the fireball.

Critical ignition energies were determined for the most common transient exterior kindling fuels. Extinguishment of ignitions by blast in most of these fuels does not occur unless peak overpressure is 5 psi or greater for a 1 sec positive phase duration. Close agreement was found between field and laboratory determinations of the ignition

energies of newspaper and pine needles. Kindling fuels adjacent to wood structures increase fire build-up. Storage of such fuels in metal trash cans and tying of newspapers in compact bundles materially reduce fire hazard. Automobiles were not found to present an immediate fire problem; however, if seat materials are frayed or worn they may smolder and flare up several hours later.

# FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

## ACKNOWLEDGMENT

Project 8.11b planning was done by Dr. Keith Arnold, Mr. Fred M. Sauer, and Mr. Craig C. Chandler. Installation of fuel specimens was done by Chandler, Arnold, and Mr. William E. Reifsnyder. Installation of weather instruments and reduction of weather data were made by Reifsnyder. Stenographic work during activities at the proving ground was done by Miss Bethel E. Webb. Over-all direction was by Mr. W. L. Fons, the project officer.

Assistance rendered by the Director of Program 8 and other personnel of the Department of Defense contributed substantially toward achieving the objectives of this project. Pre- and post-shot documentary still photography and motion pictures at shot time were made by Program 9.

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## ILLUSTRATIONS

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# CHAPTER 1

## INTRODUCTION

### 1.1 OBJECTIVES

Project 8.11b, Operation UPSHOT-KNOTHOLE, is part of a research program sponsored by the Armed Forces Special Weapons Project which seeks to predict the extent and distribution of primary ignitions that may result from atomic explosions over wildland and urban target areas. Mass-fires, fire storms, and conflagrations may produce the principal damaging effect on urban targets following atomic attack. Probability that these mass-fires will occur depends on extent and distribution of ignitions as well as fuel, topographic, and weather conditions. A knowledge of the fire susceptibility of a potential target is important to offensive and defensive military operations and also to civil defense.

A large percentage of primary ignitions will occur in kindling fuels which will in turn ignite heavier fuel incapable of being ignited directly by thermal radiation. The number of ignition points is determined by distribution of kindling fuels and their ignition energies at the moisture content determined by weather conditions.

This project was designed to:

1. Determine minimum thermal energies required to ignite those transient exterior kindling fuels found to be dominant by survey of six large representative cities.
2. Study blast effects on persistence of ignition of these fuels.
3. Obtain preliminary information on build-up and spread of primary fires, and provide photographic stock-footage demonstration material of the ignition of heavy combustible structures by transient exterior fuels.

Present studies are confined to ignition effects of smaller weapons (yields from 10 to 100 KT). It is believed, however, that with additional laboratory and theoretical work much of these field data can be extended to predict incendiary effects of larger weapons.

## 1.2 BACKGROUND

### 1.2.1 General

Experimental evidence indicates that solid wood surfaces and wood products ignited on one side by a heat source do not continue to burn when the heat is removed. This phenomenon is particularly true when the heat source is an extremely short radiant pulse from an atomic detonation. Surfaces may char heavily or even produce flame during application of radiant energy; however, in the absence of other energy sources ignition does not continue and may die out even before arrival of the shock. Such an ignition is spurious, and is not important in contributing to conflagration potential.

Thin materials, of the order of 1/100 in. thickness, however, once ignited, continue to burn until consumed. Such materials may contribute to the ignition of heavier fuels in two ways:

1. Critical energy for persistent ignition is substantially lower in the presence of a pilot flame than for self-ignition. Thin fuels ignited early in the thermal pulse may serve as a pilot flame for heavier materials. This effect is important in composite fuels where the presence of only a small quantity of thin material may serve to sustain ignition that would otherwise not continue.
2. If sufficient thin material is present, fire may spread to adjacent combustibles by successive ignitions after the thermal pulse has died out.

Thin materials which behave in the above manner are termed kindling fuels.

Rotted wood and decay pockets found in thick fuels also act as kindling materials. Such kindling fuels, even though thick dimension-wise, have very low density resulting in low critical ignition energy values.

Project 2.2, Operation BUSTER[1] and Project 8.1, TUMBLER-SNAPPER[2], working with forest fuels, established ignition energies for thin materials and for low density materials such as rotted wood far beyond the range of substantial blast damage.

With forest fuel characteristics[3] as indicators of kindling materials, urban kindling fuel surveys were made by Projects 8.11a and

---

1/ R. K. Arnold and W. L. Fons, Thermal and Blast Effects on Idealized Forest Fuels. Forest Service, U. S. Dept. of Agriculture, 20 March 1952, Operation BUSTER Project 2.2. WT-309. SECRET.

2/ Keith Arnold, Effects of Atomic Explosions on Forest Fuels. Forest Service, U. S. Dept. of Agriculture, April-June 1952, Operation SNAPPER Project 8.1, WT-506. CONFIDENTIAL.

3/ G. M. Byram and others, Thermal Properties of Forest Fuels. Forest Service, U. S. Dept. of Agriculture, October 1952. AFSWP Interim Technical Report 404. 34 pp.

8.11b personnel[4]. Kindling fuels were classified as primary ignition points when they were in a position where exposure to a fireball was probable and when they were large enough to spread fire to combustibles that were not kindling fuels. Table 1.1 presents the relative occurrence of common exterior kindling materials that represent an average for six large U. S. cities. Table 1.2 presents the relative occurrence of common types of automobile seat covering materials based on a sample of 900 vehicles from one city.

Samples of materials listed in Tables 1.1 and 1.2 were collected and duplicated in quantity for laboratory source tests and for tests during UPSHOT-KNOTHOLE. Kindling fuels found inside buildings were concurrently tested by Project 8.11a. The Forest Products Laboratory at Madison, Wis., determined minimum energies (approximately 1 sec pulse) for persistent ignition of test materials by exposure to the Forest Service 12 in. laboratory source.

TABLE 1.1 - Relative Occurrence of Transient Exterior Kindling Fuels

| Exterior Kindling Fuels | Relative Occurrence | |
|---|---|---|
| | Commercial Areas (%) | Residential Areas (%) |
| Grass and leaves | 1.7 | 10.7 |
| Newspaper | 59.0 | 66.3 |
| Wrapping paper | 8.9 | 2.6 |
| Paper bag | 2.0 | 2.5 |
| Fiberboard carton | 8.3 | 5.6 |
| Rag | 1.6 | 3.0 |
| Mop | 0.1 | 2.5 |
| Awning | 16.8 | 5.2 |
| Miscellaneous | 1.6 | 1.6 |

4/ Craig C. Chandler and Keith Arnold, Distribution of Primary Ignition Points Following Atomic Attack on Urban Targets--Transient Exterior Fuels. Forest Service, U. S. Dept. of Agriculture, March 1953. AFSWP Interim Technical Report 412. 54 pp.

TABLE 1.2 - Relative Occurrence of Automobile Seat Upholstery Materials[a]

| Material | Relative Ocuurrence (%) |
|---|---|
| Cloth[b] | 35.0 |
| Plastic | 35.0 |
| Fiber | 26.0 |
| Leatherette | 4.0 |

[a] Includes commercial vehicles

[b] Wool and cotton materials combined

CHAPTER 2

# EXPERIMENT DESIGN

## 2.1 IGNITION STUDIES

### 2.1.1 Transient Kindling Fuels

On the basis of the urban fuel survey and laboratory ignition energy tests, 11 transient urban kindling fuel arrangements were selected for exposure to Shot 9 (8 May). These were:

1. Crumpled newspapers
2. Paper bags
3. Wrapping paper
4. Awning canvas
5. Cotton string scrub mops
6. Rags, mixed colors
7. Pine needles
8. Fiberboard carton containing crumpled newspaper
9. Fiberboard carton, empty
10. Trash can containing crumpled newspaper
11. Newspaper--folded and tied in a 10-in. high bundle

Items 1 to 7 were arranged in wooden trays 24 in. square and 3-1/4 in. deep, and covered with 2 in. mesh chicken wire (Fig. 2.1). All materials in trays were exposed perpendicular to the incidence of thermal radiation of the bomb. Additional trays of crumpled newspapers and pine needles were placed on the ground horizontally. These trays were exposed on Shot 9 at 11 stations over a thermal range from 29.5 to 2.3 cal/sq cm[1].

### 2.1.2 Automobile Seat Coverings

Automobiles are abundant in urban areas of the United States, and their upholstery and seat covers may be important sources of kindling fuels. Most automobile seat upholstery and seat covers are cotton, wool, fiber, plastic, or leatherette, and seat stuffing is either

1/ Thermal energy values in this report are from WT-782, Summary Report of Technical Director, Military Effects Program. SECRET--RD.

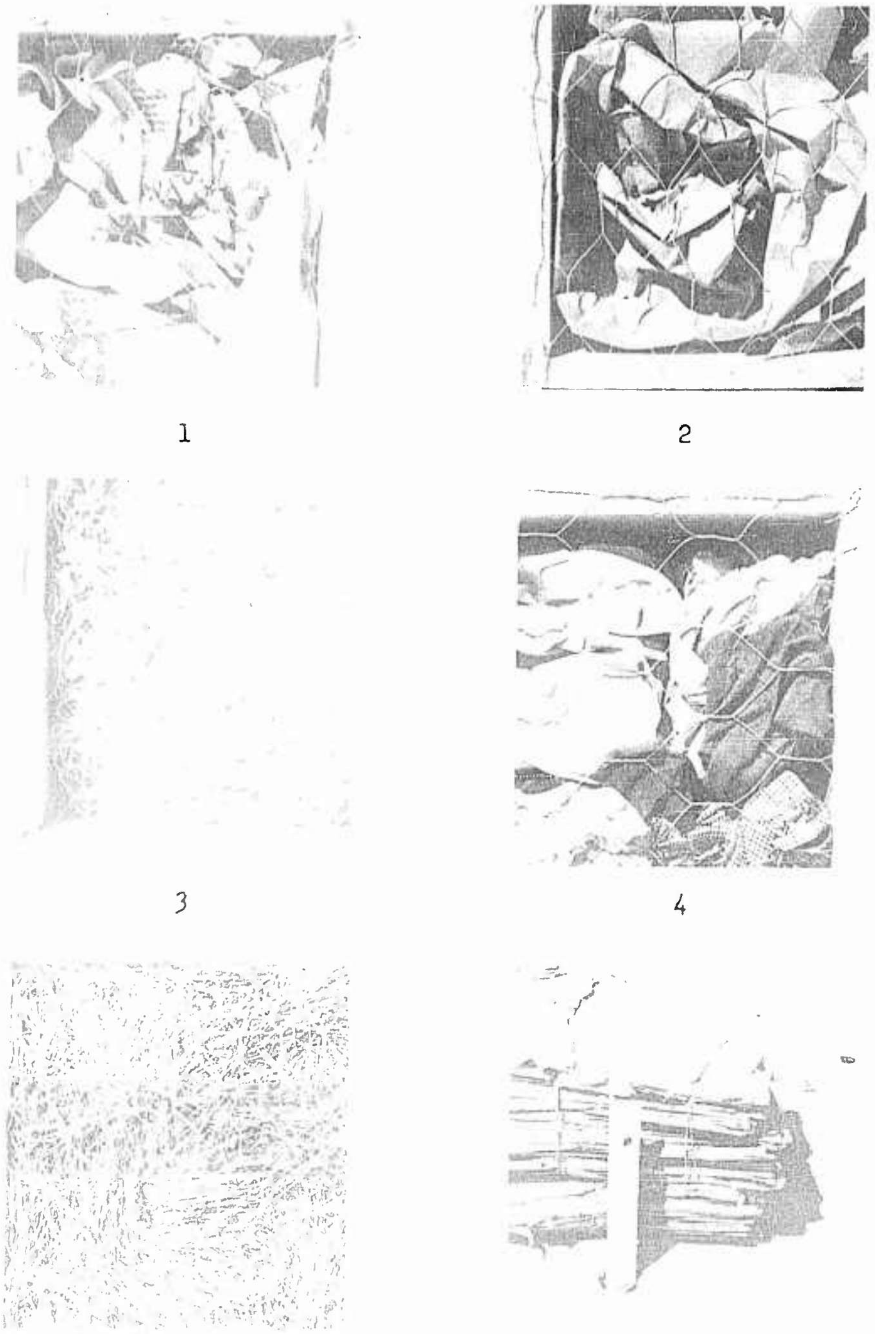



Fig. 2.1 Typical Arrangements of Transient Kindling Fuels Exposed on Shot 9: 1. Crumpled newspaper; 2. Wrapping paper; 3. Cotton string scrub mops; 4. Rags, mixed colors; 5. Pine needles; 6. Newspapers--folded and tied in 10-in. high bundle.

cotton batting or foam rubber. Automobile seat displays were prepared in 1 ft by 2 ft by 4 in. deep wooden boxes filled with combinations of stuffing material (Table 3.4). These seat displays (Fig. 2.2) were exposed on Shot 9 at six stations over a thermal energy range from 29.5 to 7.7 cal/sq cm.

Examination by project personnel of thermal damage to automobiles exposed during Shot 4 (6 April) by Program 26, Civil Effects Group, showed that some seats were ignited at thermal energy levels substantially lower than minimum laboratory ignition energies for comparable seat cover material. Since these phenomena might have occurred because of small rips or abrasions that exposed the stuffing, seat covers on four seat display boxes were ripped to expose stuffing materials. These seat displays were exposed on Shot 9 at three stations as shown in Table 3.4.

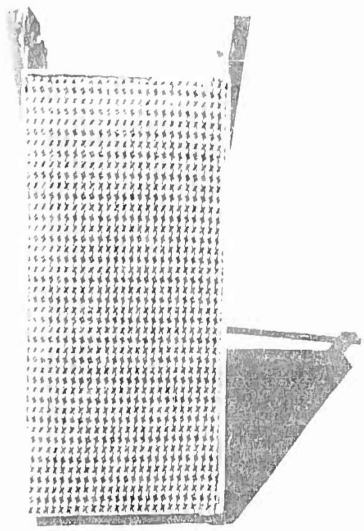


Fig. 2.2 Automobile Seat Display with Fiber Covering over Cotton Upholstery and Foam Rubber Stuffing

As a check on the seat display boxes, four used automobile seats (Fig. 3.1) were re-covered with materials shown in Table 3.4 and exposed on Shot 9 where total thermal energy was 12.2 cal/sq cm. Adjacent to each seat, two display boxes identical in stuffing, upholstery, and seat cover to the car seat were exposed. One of the pair of seat displays was ripped to expose stuffing.

In cooperation with Civil Effects Group personnel 18 cars were exposed on Shot 9 in six groups of three each over a thermal energy range of 16.0 cal/sq cm to 6.3 cal/sq cm. Orientation of cars in each group was facing, broadside, and facing away from ground zero (Fig.3.2). There were no defects in any of the seat coverings that were visible to the fireball.

## 2.2 FIRE STUDIES

### 2.2.1 Fence Sections

In order to provide preliminary information on fire build-up and burning rates following ignition, and to obtain photographic stock-footage demonstration material showing spread of fire from kindling fuels to combustible structures, nine fence sections were placed at a distance where thermal energy was 12.2 cal/sq cm on Shot 9 and 6.9 cal/sq cm on Shot 10 (25 May).

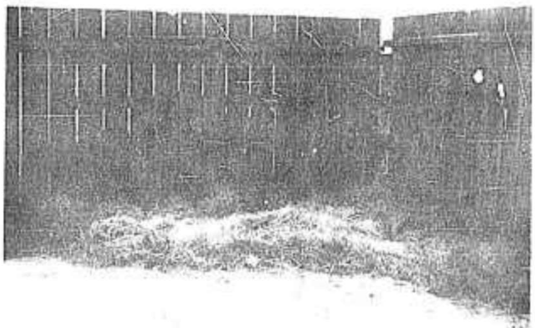
Eight fence sections, severely weathered, were obtained from a condemned residential area in Oakland, Calif. These fences contained a mixture of hardwood and softwood lumber with redwood and Douglas-fir predominating. Since badly deteriorated boards had been replaced over the years, evidences of weathering were not uniform. However, every board showed some signs of dry rot. One fence section, identical in design to the weathered fences, was made of new Douglas-fir lumber.

To prevent collapse following exposure to the blast wave, fence sections were nailed to a backing frame supported on 4 by 4 wood posts.

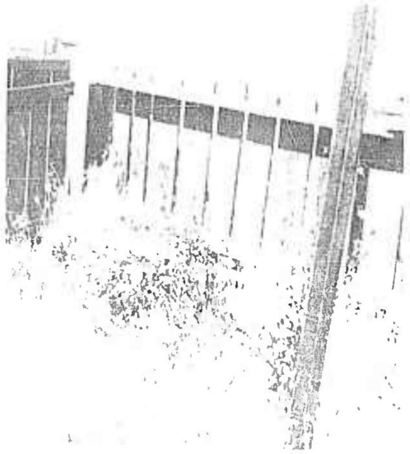
Transient kindling fuels were placed near fence sections (Table 3.5) in a manner simulating the average of worst ignition hazard conditions normally found in cities (see Figs. 2.3, 2.4 and 2.5). These materials had to be held in place by chicken wire during high winds prior to D-day. The new fence and one weathered fence in which rotted wood itself served as a kindling fuel had no transient kindling materials near them.

### 2.2.2 Automobiles

In order to study rate of build-up, duration of burning and intensity of fire produced by simultaneous ignition of several automobiles, a compact group of 13 cars was established at a distance where total thermal energy was 12.2 cal/sq cm. Seat covers of each of these cars were ripped to expose stuffing to the fireball and produce maximum ignition hazard and fire build-up conditions (Fig. 3.5).

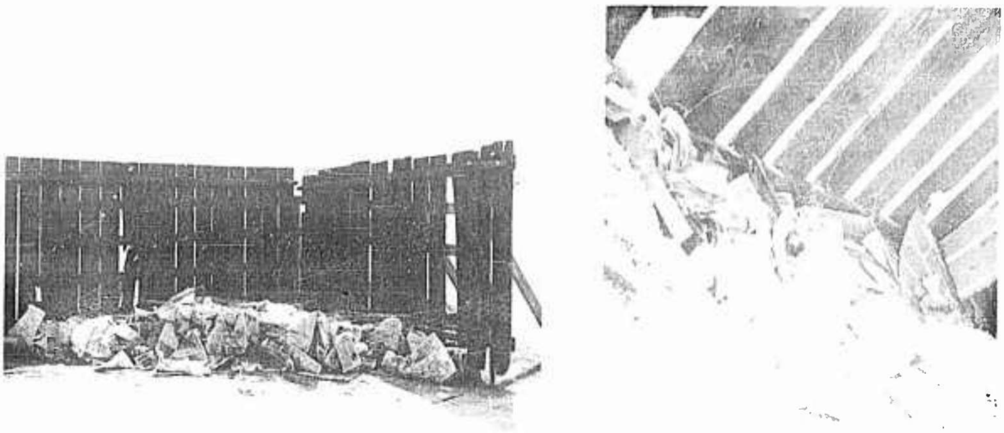


Test Fence No. 1



Portion of Fence in City

Fig. 2.3 Comparison of Grass Accumulations



Test Fence No. 2 Portion of Fence in City

Fig. 2.4 Comparison of Newspaper Accumulations

Test Fence No. 7 Wood Building in City

Fig. 2.5 Comparison of Trash Cans Containing Paper Accumulation

## 2.3 METHODS OF EVALUATING RESULTS

### 2.3.1 Photography

Pre-shot and post-shot documentary photographs of all installations and 16-mm color motion pictures (16 frames/sec) of automobile seats and fence sections were made by Program 9. Continuous motion picture coverage of automobile seats and fence sections was obtained from H - 5 sec until approximately H + 2 min. Intermittent cameras operated from H - 5 to H + 30 sec, then 5 sec each minute for 20 min.

To study fire build-up at stations not covered by photography a helicopter reconnaissance survey started at H + 5 min by a party consisting of pilot, cameraman, monitor and two project observers. The observers recorded evidences of burning and described fires on a voice recorder. The transcribed record is presented in Appendix A.

The main reconnaissance and recovery party entered the target area at approximately H + 1-1/2 hr. This group recorded detailed information on the extent of fire damage to thermal specimens.

### 2.3.2 Weather and Fuel Moisture

Temperature, relative humidity, and wind velocity were continuously recorded at about the mid-point of the Forest Service line for 8 days prior to D-day. Samples for fuel moisture verification were collected from exposed fuels on the line at approximately H-hour on D - 6 to D - 2 days. Since equilibrium moisture contents corresponding to shot time relative humidity (19 per cent) were considered to be the most reliable estimate of fuel moisture, they were determined from appropriate equilibrium data[2/].

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2/ W. L. Fons. A Mathematical Study of Rate of Spread of Surface Fires in Ponderosa Pine Needles. Unpublished Report, available in Forest Service files, California Forest and Range Experiment Station, Berkeley, Calif. June 1935. 22p.

International Critical Tables, Vol 2, p 323.

## CHAPTER 3

## RESULTS

### 3.1 IGNITION STUDIES

#### 3.1.1 Transient Kindling Fuels

A summary of ignition results for kindling fuels exposed on Shot 9 is displayed in Table 3.1. Similar data for Shot 4 and Shot 10 are found in Tables 3.2 and 3.3.

#### 3.1.2 Automobile Seat Coverings

A summary of ignition results for automobile seats and seat displays exposed on Shot 9 is shown in Table 3.4. Figure 3.1 shows damage to car seats where thermal energy was 12.2 cal/sq cm.

Although no fire was visible from the helicopter at H + 22 min in any of the three car groupings, one was ignited at 12.2 cal/sq cm and burned completely. This car (Fig. 3.2), with the rear window missing and facing away from ground zero, had gray wool upholstery.

Fig. 3.1 Automobile Seats with Corresponding Seat Displays Exposed to 12.2 cal/sq cm--Shot 9

TABLE 3.1 - Thermal Effects on Kindling Fuels Exposed Normal to Incident Radiation--Shot 9

| Fuel | Moisture Content | Total Thermal Energy (cal/sq cm) | | | | | | | | | | | Ignition Energy (cal/sq cm)[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 29.5 | 23.5 | 16.0 | 12.2 | 9.7 | 7.7 | 6.3 | 4.3 | 3.1 | 2.6 | 2.3 | |
| | | Thermal Effects[b] | | | | | | | | | | | |
| Crumpled newspaper | 3.1 | B | B | B | B | B | B | B | B | SC | N | N | 4.0 |
| Crumpled newspaper[a] | 3.1 | E | E | E | C | C | C | SC | N | N | | | - |
| Newspaper bundle | 3.1 | C | C | C | C | B | C | C | SC | | | | - |
| Trash can with papers | 3.1 | | | | E | B | B | B | SC | | | | 6.0 |
| Fiberboard carton with papers | 3.1 | E | E | C | B | B | B | C | SC | N | | | 7.0 |
| Fiberboard carton | 4.6 | E | C | C | C | C | N | | | | | | |
| Paper bags | 4.6 | E | B | B | B | B | B | B | SC | N | | | 6.0 |
| Wrapping paper | 4.6 | B | B | B | B | B | B | B | SC | | | | 6.0 |
| Awning canvas | 3.6 | L | L | L | B | C | SC | B | SC | | | | 11.0 |
| Mops, cotton string | 3.6 | B | B | B | B | B | B | B | B | B | B | N | 2.5 |
| Rags | 3.6 | B | B | B | B | B | B | B | B | N | | | 4.0 |
| Pine needles | 4.4 | B | E | B | C | B | B | C | N | | | | 7.5 |
| Pine needles[a] | 4.4 | E | E | SC | N | N | N | N | | | | | - |

[a] Trays placed on ground horizontally. All other trays exposed normal to incident radiation.

[b] Code letters as follows:

- B--fuel consumed by burning
- C--charred
- E--fuel ignited but extinguished by blast
- L--lost to blast
- N--no visible effect
- SC--slightly charred

[c] ± 0.5 cal/sq cm.

TABLE 3.2 - Thermal Effects on Kindling Fuels Exposed Normal to Incident Radiation--Shot 4

| Fuel | Moisture Content | Total Thermal Energy (cal/sq cm) | | | |
|---|---|---|---|---|---|
| | | 4.8 | 4.0 | 3.4 | 2.5 |
| | | Thermal Effects[a] | | | |
| Crumpled Newspaper | 3.6 | B | B | SC | N |
| Newspaper bundle | 3.6 | SC | SC | SC | N |
| Fiberboard carton | 5.2 | | | N | |
| Wrapping paper | 5.2 | SC | | N | |
| Mops, cotton string | 4.2 | B | | B | |
| Rags | 4.2 | B | | N | |
| Pine needles | 5.4 | N | | | |

[a] Code letters as follows:
B--burned; C--charred; SC--slightly charred

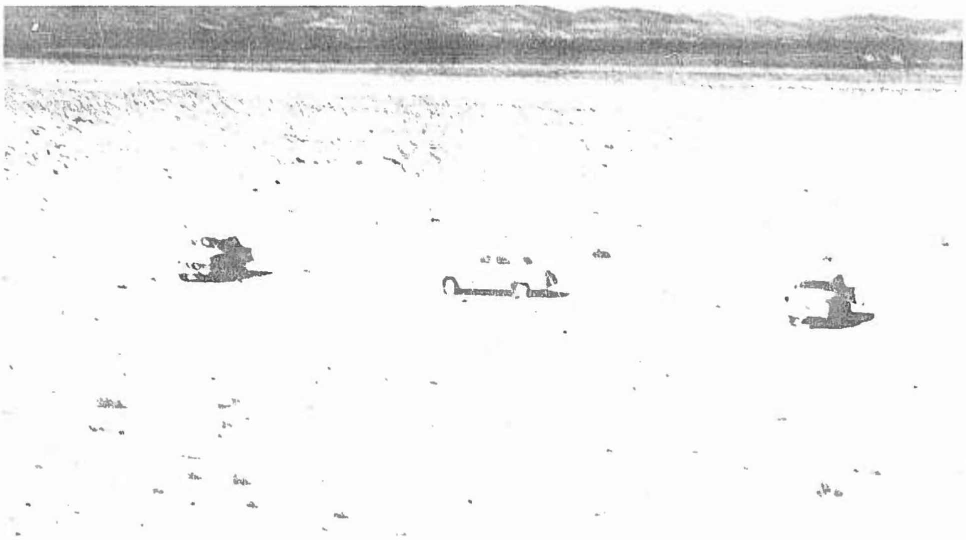

Fig. 3.2 Three-car Group at H + 22 min. Car at Extreme Right Was Burning Vigorously at H + 1-1/2 hrs--Shot 9

TABLE 3.3 - Thermal Effects on Newspapers and Pine Needles in Relation to Angle of Exposure--Shot 10

| | Ponderosa Pine Needles (Moisture content 5.8%) | | | Crumpled Newspapers (Moisture content 4.2%) | | |
|---|---|---|---|---|---|---|
| | | Thermal effects[d] | | | Thermal effects[d] | |
| Angle[a] | En[c] | W[e] | W/O[f] | En[c] | W[e] | W/O[f] |
| N[b] | 31 | B | C | 9.2 | B | B |
| 60 | 29 | B | C | 8.7 | B | B |
| 45 | 24 | C | C | 6.5 | B | B |
| 30 | 20 | C | C | 5.4 | B | B |
| 0 | 4.5 | C | C | 0.8 | C | B |
| N[b] | 16.5 | B | B | 6.9 | B | B |
| 60 | 15 | B | B | 6.5 | B | B |
| 45 | 13 | B | B | 5.5 | B | B |
| 30 | 9.5 | B | B | 3.8 | B | B |
| 0 | 2 | C | C | 0.4 | N | C |

[a] Measured from ground surface.

[b] Exposed normal to incident radiation. Energy value describes station location.

[c] Normal energy computed by cosine law (cal/sq cm).

[d] Code letters as follows:
B--burned; C--charred; N--no visible effect

[e] Fuel bed covered with chicken wire.

[f] Chicken wire removed from center of fuel bed.

TABLE 3.4 - Thermal Effects on Automobile Seats and Seat Displays--Shot 9[a]

| Seat Cover[b] | Upholstery Fabric[c] | Stuffing[d] | Total Thermal Energy (cal/sq cm) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 29.5 | 23.5 | 16.0 | 12.2 | 9.7 | 7.7 |
| | | | Thermal Effect[f] | | | | | |
| None | Cotton | CB | | B | B | B | | C |
| None[e] | Cotton | CB | | | | B | | |
| None | Cotton, slit | CB | | | | B | | B |
| None | Cotton | FR | | B | | B | C | |
| None[e] | Cotton | FR | | | | B | | |
| None | Cotton, slit | FR | | | | B | C | |
| None | Wool | CB | C | C | C | SC | | |
| None | Wool | FR | C | C | C | SC | | |
| Plastic | Cotton | CB | C | C | C | C | | |
| Plastic | Cotton | FR | C | C | C | C | | |
| Fiber | Cotton | CB | C | C | C | C | | |
| Fiber[e] | Cotton | CB | | | | C | | |
| Fiber, slit | Cotton, slit | CB | | | | B | | B |
| Fiber | Cotton | FR | C | C | C | C | | |
| Fiber[e] | Cotton | FR | | | | C | | |
| Fiber, slit | Cotton, slit | FR | | | | C | C | |

[a] Estimated moisture content of wool and cotton at H-hour: 4%.

[b] Plastic--Lumite #543; Fiber--Southern Fabrics, Inc. #914.

[c] Cotton--heavy green herringbone; Wool--C.T.B. 69 Taupe.

[d] CB--cotton batting; FR--foam rubber.

[e] Automobile seats.

[f] B--burned; C--charred; SC--slightly charred.

## 3.2 FIRE STUDIES

### 3.2.1 Fence Sections

All weathered fence sections (Table 3.5) burned completely on Shot 9 at an energy level of 12.2 cal/sq cm. The new fence section only charred slightly on Shot 9, but on Shot 10, with an accumulation of newspapers in front, burned completely at 6.9 cal/sq cm. View from helicopter (Fig. 3.3) shows variations in amount of fence sections remaining at H + 21 min. By H + 1-1/2 hrs all weathered fence sections were completely consumed. From time-sequence motion pictures beginning at time of ignition of the kindling fuel, an estimate was made of the relative amount of material consumed with time for all weathered fence sections (Fig. 3.4) except fence 6 which was not in view of the camera.

Detailed studies of motion pictures show:

> Just prior to shock arrival newspapers, grass and papers in the trash can were burning.
>
> On shock arrival there was a definite increase in flame height from the grass at fence 1 and newspapers at fence 2.
>
> One-half second after shock arrival flame from the grass had apparently died out, flame from newspapers at fence 2 continued to build up, and flame from newspapers at fence 3 increased in height.
>
> Two and one-half seconds after shock arrival dust obscured the fences. Between detonation time and this instance no other flames were visible in the pictures except for instances noted above.
>
> H + 1-1/2 min, dust began to clear and flame could be seen on fences 2 and 3.
>
> H + 5-1/2 min, unburned papers near fence 3 were ignited from burning fence material.
>
> H + 8-1/2 min, unburned papers near fence 2 were ignited from burning fence material. Except for fences 2 and 3, flames were not visible.

### 3.2.2 Automobiles

From the helicopter at H + 22 min fire was observed in only two cars in the rear row of the compact group. However, later study of photographs (Fig. 3.5) showed that at least two other cars were also burning at this time. By H + 1-1/2 hrs all cars except one were burning.

TABLE 3.5 - Fence Sections--Characteristics

| Fence | Kindling Fuel | Orientation Ground Zero → |
|---|---|---|
| 1 | Grass | |
| 2 | Newspaper | |
| 3 | Newspaper | |
| 4 | Newspaper | |
| 5 | Fiberboard carton | |
| 6 | Fiberboard carton with newspaper | |
| 7 | Trash can with newspaper | |
| 8 | None | |
| 9[a] | None | |

[a] New wood, Douglas-fir

Fig. 3.3 Fence Sections at Approximately H + 21 min--Shot 9

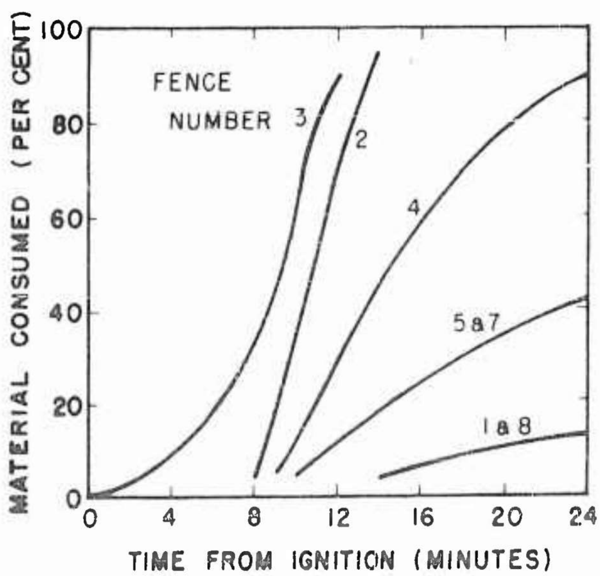


Fig. 3.4 Comparison of Amounts of Material Consumed with Time for Fences Exposed--Shot 9

Fig. 3.5 Compact Group of 13 Cars at H + 22 min, Thermal Energy 12.2 cal/sq cm--Shot 9

CHAPTER 4

# DISCUSSION

## 4.1 IGNITION STUDIES

### 4.1.1 Transient Kindling Fuels

In order to determine minimum critical ignition energies for these fuels, low, stable relative humidities were required to produce low fuel moistures and optimum burning conditions. For Shot 9 relative humidity reached a maximum of 34 per cent at H - 3 hrs, and dropped to 19 per cent at H-hour with an air temperature of 63°F. These conditions were nearly ideal for achieving ignition-energy objectives.

Minimum ignition energies were established (Table 3.1) for most kindling fuels exposed normal to the radiant flux, except for newspaper bundles and fiberboard cartons which did not burn at a thermal energy level of 29.5 cal/sq cm. Ignition energies were estimated by interpolation between stations to the nearest 0.5 cal/sq cm by evaluating post-shot char conditions of the fuel at the next lower calorie level. A closer estimate was made for mops (2.5 cal/sq cm) because of the small thermal increment between far-out stations. Ignition of awning canvas at 6.3 cal/sq cm was ignored in determining the ignition energy level because only slight charring resulted at slightly higher energy levels.

Limited participation on Shot 4 was intended to confirm laboratory measurements and to test exposure methods prior to Shot 9. Entries of Table 3.2 (Shot 4), compatible in all respects with data of Table 3.1, lend support to the validity of results obtained on Shot 9.

Field ignition energies for newspaper and pine needles are compared with laboratory values in Figs. 4.1 and 4.2. Data for these fuels were selected for comparison, because complete laboratory tests had measured variation of ignition energy with moisture content. These laboratory exposures were made by the Forest Products Laboratory using the Forest Service 12 in. x 12 in. source at 2600°K. Data on pine needles represent samples taken from both newly fallen and one to two year old needles. Field ignition energies can only be specified between the lowest ignition value (B) and the highest non-ignition value (C) due to finite spacing of fuels during exposure. Interpolation

between large differences in these energies is difficult since ignition is a liminal process. BUSTER[1] data do not provide a critical value since the lower limit (non-ignition) was not determined.

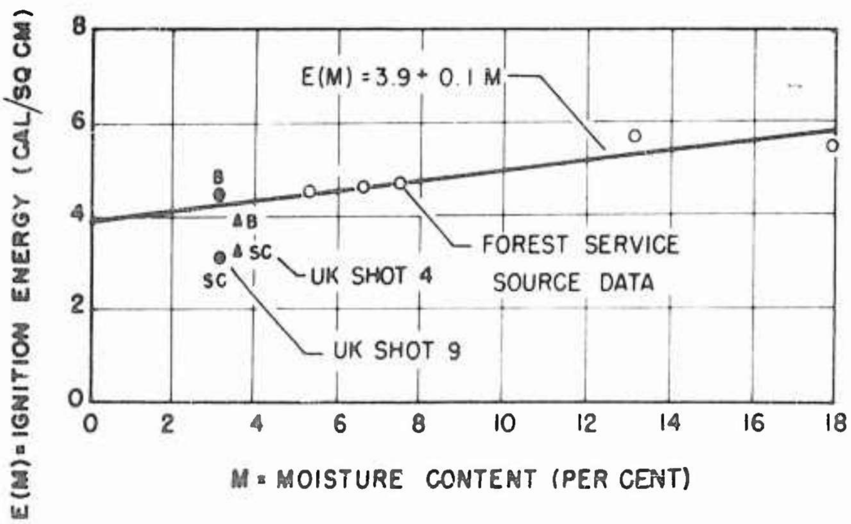


Fig. 4.1 Critical Ignition Energy for Sustained Burning--Crumpled Newspaper, Approximately 0.004 in. Thick, Used but Unweathered. Exposure normal to incident radiation. B--burned; SC--slight char.

Field exposures of pine needles made on various shots allow comparison of data obtained under various fuel moisture conditions. Fuel moisture values shown in Fig. 4.2 for TUMBLER-SNAPPER are lower than values quoted in WT-506[2] which were determined from sampling fuel beds located approximately 8 miles from the exposed beds. Under conditions of falling humidity, such as existed at shot times, fuel moisture of the bed lags behind that of the surface. Since ignition takes place on those surfaces most exposed and since moisture contents of these surfaces will follow closely the change of relative humidity, equilibrium moisture content values were used in reducing all data. Using these equilibrium moisture contents agreement between critical ignition energy as determined in the laboratory and in the field is excellent.

This close correlation of laboratory and field results must be interpreted with consideration of possible effects of pulse shape, spectral distribution of incident radiation, and other theoretical aspects of the ignition problem. Distribution of radiant energy received from the laboratory source corresponds spectrally to a Plankian temperature

1/ Arnold and Fons, op. cit., p. 18.
2/ Arnold, op. cit., p. 9.

of 2600°K. The time average spectral distribution of energy received from the weapon corresponds to a Plankian temperature of 6000°K. Using these two spectra the total absorbtance of typical unexposed forest fuels is 30 to 40 per cent higher for the weapon as compared to the laboratory source. As charring occurs prior to ignition, absorbtance approaches 90 per cent irrespective of wave length, and differences due to radiation spectra are minimized. Hence the difference in ignition energy due to source spectra is expected to be less than that indicated by absorbtance measurements made on unexposed specimens.

The radiant pulse associated with the weapon is considered to be less effective than a square wave pulse due to the "tail" which contains considerable energy emitted at low intensity. It is possible that this effect may counter the increased weapon effectiveness due to spectral distribution. This, however, may not be the case for fuels with different absorbtance spectra.

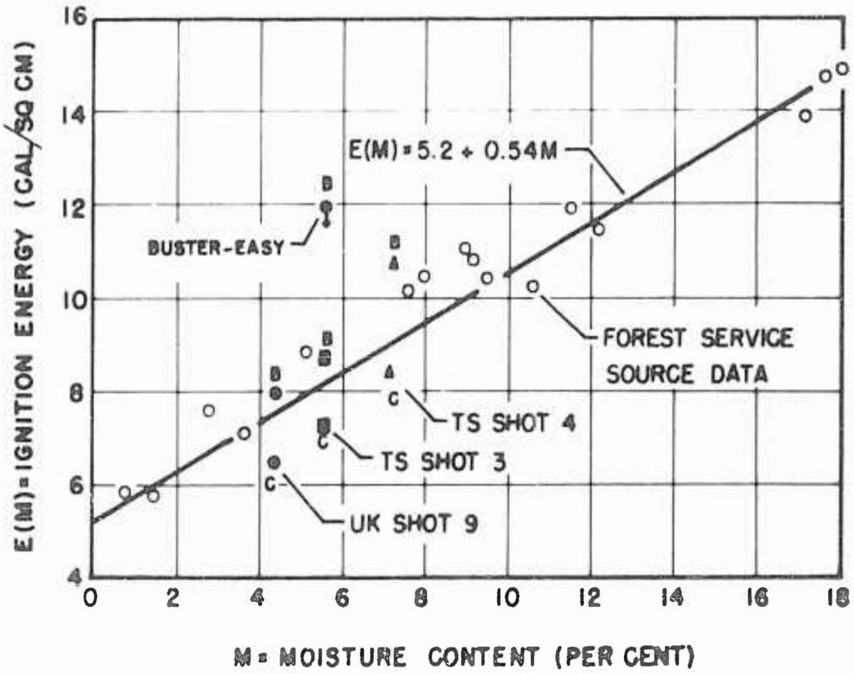


Fig. 4.2 Critical Ignition Energy for Sustained Burning--Ponderosa Pine Needles. Exposure normal to incident radiation. B--burned; C--charred.

Theoretical variation of ignition energy with moisture content may be approached by an elementary analysis which considers the fuel element to contain no temperature gradient and moisture contributing only through the latent heat required for vaporization. This analysis indicates that variation of ignition energy with fuel moisture follows the relation

$$E(M) = E_o(1+CM)$$

where E(M) is the ignition energy at moisture content, M, $E_0$ is the ignition energy at zero moisture content, and C is a constant independent of fuel type. Experimentally determined ignition energies appear to follow the above relationship for all moisture contents less than approximately 20 per cent. The slope of energy versus moisture is smaller for newsprint than pine needles as would be expected due to its lower ignition energy at zero moisture. Discussion of this analysis is not carried further except to note that constants derived from experimental data are apparently incompatible between fuels.

Critical energy values for hygroscopic materials have little meaning unless moisture contents are specified. Furthermore, in many cases practical application will require that the critical energy-moisture content relation be known. Consider pine needles (by comparison only a moderately high ignition energy), here the variation in energy may be 2:1 between extremes in weather conditions. On the other hand newspaper, having a low ignition energy level and only one-fifth the variation with moisture content as pine needles, represents a hazardous material under most weather conditions.

Newspaper and pine needles exposed horizontally did not burn at the highest calorie level on Shot 9. For those fuels where the fuel bed was not consumed, distinction between charring (non-ignition) and extinguishment (ignition and subsequent blow-out by blast) was based on burned fuel particles remaining in the bed. When these two effects occurred at adjacent stations difficulty in interpretation was encountered due to the possible removal of burned material from the bed by the blast. In order to evaluate thermal effects for horizontal beds Table 4.1 was prepared by computing the energy falling normal to the bed by use of the cosine law.

The severity of thermal effects (from no effect to charring to burning) appears to increase with energy level in a regular manner for pine needles; however, for newspaper below 4.3 cal/sq cm effects were irregular. Since these fuels are composed of surfaces presenting infinite orientation possibilities to incident radiation the cosine law was not expected to apply. Thermal damage to fabric (Project 8.11a) was found to be influenced by chicken wire screen placed in front of the sample to prevent sample removal by blast. The shadow cast by the wire was magnified by heat conduction within the material to form a non-damaged area of 1/8 to 1/4 in. wide for normal exposure. Since this shadow increases in width as the cosine of the angle of exposure the apparent cosine effect may have been caused by the wire.

To test this hypothesis a limited number of samples were exposed at various angles during Shot 10 (Table 3.3) with and without the wire. Where fuels were not extinguished, results indicate no effect of wire whenever normal energy, as computed using the cosine law, was greater than the critical ignition energy. For grazing angles results were inconclusive; more complete experimental data and study are required. However, this problem is not important under operational conditions, for sufficient surface irregularities and fuel orientations are expected to provide a large percentage of ignition points at greater than grazing angles. Shots 9 and 10 results indicate that whenever energy normal to

the bed is greater than critical, ignition always occurs, but there may be ignition when normal energy is less than critical and the bed surface is not perpendicular to incident energy. This complication arises from irregularities of fuel particles and fuel bed arrangement.

TABLE 4.1 - Thermal Effects on Pine Needle and Newspaper Beds--Shot 9--Energy Normal to Fuel Bed Computed by Cosine Law

| Energy cal/sq cm | Thermal Effects[a] | | Energy cal/sq cm | Thermal Effects | |
|---|---|---|---|---|---|
| | Pine Needles | Newspaper | | Pine Needles | Newspaper |
| 23.5 | E - P | B - P | 4.3 | N - P | B - P |
| 16.0 | B - P | B - P | 3.7 | N - H | C - H |
| 13.0 | E - H | E - H | 3.1 | -- | SC - P |
| 12.2 | C[b]- P | B - P | 2.6 | -- | N - P |
| 9.7 | B - P | E - P | 2.5 | N - H | C - H |
| 9.1 | E - H | E - H | 2.3 | -- | N - P |
| 7.7 | B - P | B - P | 1.8 | N - H | C - H |
| 6.3 | C - P | B - P | 1.3 | N - H | SC - H |
| 5.4 | SC - H | E - H | 0.8 | -- | N - H |

[a] Code letters as follows:
- B--fuel consumed by burning
- C--charred
- SC--slightly charred
- N--no visible effect
- E--fuel ignited but extinguished by blast
- P--fuel bed exposed normal to incident radiation
- H--fuel bed exposed horizontally

[b] Observation in doubt

### 4.1.2 Extinguishment of Ignitions by Blast

Results gathered on TUMBLER-SNAPPER indicated that fuels ignited by the thermal pulse were extinguished by the shock only at close-in stations. Laboratory experiments[3], using a modified shock tube with a

3/ V. N. Tramontini and P. R. Dahl, Forest Fuels Blast Studies. University of California, Los Angeles, Dept. of Engineering, June 1953. Interim Report 53-15. 134 pp.

linear velocity decay, determined the magnitude and relationship of shock wave-fuel parameters necessary for blow-out. Due to variations in arrangement of individual fuel particles in fuel beds, blow-out must be treated on a statistical basis. For a 50 per cent chance of extinguishment by blast, laboratory measurements result in a relationship

$$V_1 t_+^{0.41} M^{0.1} = C + 7.6 t_A$$

where $V_1$ is the peak particle velocity (ft/sec)

$t_+$ is positive phase duration (sec)

$M$ is moisture content (per cent)

$t_A$ is time of shock arrival (sec)

$C$ is a constant, dependent on the fuel, its compactness and orientation to the blast.

Under exposure conditions of UPSHOT-KNOTHOLE Shots 9 and 10 the overpressure (corresponding to peak particle velocity from the above equation) required for 50 per cent probability of blow-out of pine needles and newspaper was of the order of 5 psi. Results of these two shots indicate that the necessary overpressure for ignition extinguishment was somewhat higher than this value. These field data can be considered only qualitatively due to the small sample exposed per station and natural variability between fuel trays in the sample. However, it appears that laboratory constants represent an overpressure level below which extinguishment will not occur. Furthermore, field work measured blow-out on stationary fuel beds. If fuels had been allowed to move under the action of shock wind even higher overpressures would be required for blow-out. Additional complex factors arise under field application such as the influence of adjacent structures and ground surface in modifying shock phenomena near fuel locations.

In view of the difficulties in establishing blow-out in the field on a probability basis and uncertainties encountered in application, it appears advisable to use laboratory data for blow-out prediction purposes. Refinement of limits of ignition extinguishment so determined would not materially change present fire damage estimates.

### 4.1.3 Automobile Seat Coverings

Thermal results (Table 3.4) on automobile seats and seat displays agree. Hence seat display ignitions can be considered indicative of ignitions to be expected in actual seats. At 12.2 cal/sq cm ignition occurred only in those seats with cotton upholstery fabric or with seat covers slit exposing the cotton stuffing. Seat displays with exposed cotton stuffing ignited at the lowest exposure level--7.7 cal/sq cm. (Note, this is not the critical energy for this material.) These data indicate that seat material will rarely ignite unless some cotton

portion of the seat material is exposed. It is possible that ignition of cotton body cloth resulted in destruction of the automobile in the three-car grouping which burned at 12.2 cal/sq cm.

The area of car seats exposed to the fireball is small, and the part of this area which is apt to be perpendicular to incident energy is even smaller. Consequently, unless transient kindling fuels, such as newspapers, are present inside or seat coverings are worn to a point where seat stuffing is exposed, automobile seat coverings rarely present a serious ignition problem.

## 4.2 FIRE STUDIES

### 4.2.1 Fence Sections

The burning of the fence sections furnished several demonstrations of the action of kindling fuels, particularly with respect to fire build-up. One weathered fence section was ignited by its own rotted material which indicates that transient kindling fuel present at other weathered fences was not the only agent responsible for ignition. In case of the new fence, however, newspaper serving as a kindling fuel was definitely the igniting agent.

Examination of time-sequence movies indicates that the main effect of kindling fuels on weathered fences was to increase the rate of fire build-up. Fire build-up, as measured by the relative amount of material of fence consumed with time (Fig. 3.4) was affected more by the kind, arrangement, and amount of kindling fuel present than by the orientation of the fence with respect to ground zero. For instance, in 12 min, fence 2 with newspaper was completely consumed whereas fence 1 barely started burning.

The fact that fences 1 and 8 burned at the same rate indicates that the grass fire contributed little to fire build-up, probably because the grass fire appeared to be extinguished by the blast wave[4]. The fiberboard carton and newspaper in the trash can also contributed little. In fact the fiberboard carton in front of fence 5 was visible in Fig. 3.3 at H + 21 min. It is evident that effective and relatively safe kindling material storage or disposal would utilize metal trash cans, covered fiberboard cartons and newspapers tied in compact bundles.

### 4.2.2 Automobiles

Two features connected with fire build-up in automobiles should be noted:

---

4/ Experience in TUMBLER-SNAPPER and BUSTER confirms this extinguishment phenomena for grasses, and also beyond the range of blast extinguishment of grass on Shot Dog of BUSTER, grass did ignite and spread fire to larger brush limbs. Thus grass remains as an important source of primary fires in wildland areas.

1. Ignition and smoldering fire in automobiles may not be discovered by cursory observation for several hours after exposure to thermal radiation.
2. Fire build-up in automobiles is a slow process and spread of fire from car to car is rare[5].

Lack of fire detection by cursory observation is not limited to automobiles, but is common to upholstered furniture and rotted wood. Helicopter observers did not detect smoke or fire in the car shown in Fig. 3.2, which later burned; at H + 35-1/2 min no smoke was visible in the left-hand blockhouse of Project 8.11a, yet the recovery party had to extinguish fire in it about an hour later; motion pictures of burning rotted logs at TUMBLER-SNAPPER show no smoke or fire for 10 to 15 min at a time. Similarly, fire was visible from the helicopter in only two cars while pictures indicated that smoke was coming from four vehicles. Nevertheless all cars in the compact group burned, and there is no evidence to suggest spread from one vehicle to another.

The compact group of cars was exposed under weather conditions which were ideal for burning; they were parked close together, and seat stuffing exposed to produce maximum hazard. Even then only two cars had burned vigorously by H + 33 min. Thus, although automobiles do not present an immediate hazard following an atomic explosion, they may smolder unnoticed for several hours before bursting into flame.

5/ This result is in agreement with actual automobile fire loss experience as reported by William J. Davis, "99.9 Per Cent Fraudulent!" <u>National Fire Protection Association Quarterly</u>, 46-2:pp. 117-123. October, 1952.

CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

1. Critical ignition energies were established for the most common transient kindling materials found in urban areas. Newspapers, which comprise approximately 60 per cent of exterior kindling fuels in cities, ignite at an energy level of 4.0 cal/sq cm when moisture content is 3 per cent--corresponding to relative humidity of 20 per cent.
2. Laboratory source measurements of critical ignition energy for newspapers and pine needles agree closely with field results when moisture content is considered.
3. Ignition will occur on inclined fuel bed surfaces whenever the energy normal to the surface (computed by cosine law) is greater than the critical ignition energy.
4. Overpressure levels for ignition extinguishment by blast wind measured in laboratory tests are lower than those experienced in UPSHOT-KNOTHOLE. In general this blow-out occurs when overpressure is greater than 5 psi for positive phase duration of 1 sec.
5. Weathered fences or other structures with rotted wood exposed provide kindling material in which primary ignition may occur.
6. Sound wood fences can be ignited by adjacent transient kindling fuels such as newspapers.
7. Large volumes of transient kindling material adjacent to fences increase rate of fire build-up. Paper stored in metal trash cans, covered fiberboard cartons, or tied in compact bundles does not contribute to initial fire build-up.
8. Automobiles do not present a serious ignition problem unless seat coverings are worn or frayed, or kindling materials such as newspapers are present inside.
9. The rate of fire build-up in simultaneously ignited automobiles parked close together is slow compared with build-up in wood structures, therefore they do not present an immediate fire problem.

## 5.2 RECOMMENDATIONS

1. Analytical investigation of critical ignition energy for thin

materials should be continued to establish basic correlations between the various parameters. Such correlation will establish the validity of present results and allow scaling to larger weapons. Analytical investigation should be paralleled by laboratory experiments conducted on homogenous materials.

2. Future field operations should include exposure of fuels at grazing angles.

3. Critical ignition energy values for hygroscopic materials should be referenced to corresponding moisture content values.

4. Defensive measures for effective kindling material storage or disposal should include use of metal trash cans, covered fiberboard cartons and newspapers tied in compact bundles.

5. Since ignition and smoldering fire in automobiles may not be discovered by cursory observation, defensive measures in large automobile parking areas should require that each car be inspected periodically after an atomic attack.

## APPENDIX A

### EDITED TRANSCRIPTION OF RECORDED OBSERVATIONS FROM HELICOPTER 1/ --Shot 9

H + 5 min. Left helipad at Control Point.

H + 12-1/2 min. Passing over burning fuel dump north of blast line. Two smokes are coming from this fuel dump; one is burning vigorously, the other is just smoldering.

H + 13-1/2 min. Circling the tree stand. No sign of any fires. It looks like about 20 trees have fallen. No fires visible in any of the Army vehicles parked close to the tree stand. No fire visible in the car behind the tree stand. No fire in the car outside the tree stand (that is, the car to the south of the stand). There is a black smoke about 1500 ft behind the tree stand burning vigorously.

H + 15 min. Approaching 29.5 cal-station 2/. There are fires close to ground zero but I can't see them too well. All fuel samples are burning at this station. Car seat displays do not seem to be burning.

H + 17 min. Approaching 23.5 cal-station. All fuel samples seem to be burned out except car seat displays which seem to be scorched but not burning. Project 8.11a house nearest the blast line is burning vigorously. The other house is structurally damaged. The two cars nearby are badly damaged but not burning. The second car seat display from the left, looking away from ground zero, is burned out but the other seems to be only scorched. All the fuel trays are completely burned out except the rags.

H + 19 min. Approaching 16.0 cal-station. Thick smoke over south of the blast line. The three cars near this station are not burning or smoking. All fuel samples are burned out except the car seat displays. The tray with rags is smoking. None of the others is smoking. No fires in the POL dump near this station.

H + 20 min. Approaching the compact group of cars. The group is blazing merrily--good smoke. The Willys station wagon in the rear row

---

1/ By W. E. Reifsnyder.

2/ Calorie levels have been substituted for distances recorded in original transcription.

is burning vigorously, although there don't seem to be any fires in any of the other cars.

H + 21 min. Approaching 12.2 cal-station. The two outermost houses of Project 8.11a are completely consumed. The middle house is not burning. The new fence is scorched but not burning. The parallel fence is burned out. All of the fences are burning or burned out except the new fence. The farthermost fence, with the grass, is not burning very vigorously. All of the others are burning quite well.

H + 22 min. Approaching the compact car group again. Two of the rear cars, the Willys and the one in the middle, are burning vigorously. The smoke is blowing toward ground zero. The three isolated cars are not burning at all. No sign of smoldering in any of the others. I think only two cars are on fire in the rear row. They may spread to the front for they are burning vigorously. There are lots of flaming rubber. I can smell the rubber. No sign of smoke in the trash can or pile of papers or other trays of newspapers at the 12.2 cal-station. Car seat at extreme right burning vigorously; the one just to the left of that is smoldering. The fence with grass has finally taken. The others are pretty well burned out, however. The fence with grass is burning but not vigorously. Parking lot is still burning vigorously.

H + 23 min. Approaching 9.7 cal-station. The cars at this station are not burning. Two car seat displays, to the left, are badly scorched. The one to the right is burning quite vigorously. The fuel tray (rags) immediately to the right of the trash can is still burning vigorously; the others are not throwing off very much smoke. Lots of yuccas burning on the hills to the south quite some distance. The trash can is burning and smoking. Cardboard box with trash has burned out; cardboard box without trash, that is, the one to the right, may be smoking but it is not burned out.

H + 24-1/2 min. Approaching 7.7 cal-station. Cardboard box with newspapers all burned out. Trash can apparently burned out. Two trays to the right, mops and rags, burning vigorously. Third to the right, pine needles, burned. One of the oil dumps near this station, the POL dump, is burning vigorously although there is only one smoke. 8.11b trays at this station starting from the left: newspapers not burning; paper bags burned out; wrapping paper burned out; canvas not burning; cardboard box not burning; cardboard box with paper burned out; trash can burned out; mops, rags and pine needles, burned out; horizontal pine needles not burned; three car seats not burned; horizontal newspaper tray not burned.

H + 26 min. Approaching 6.3 cal-station. Newspapers possibly smoldering. Canvas blown out. Trash barrel burned out.

H + 28 min. Approaching 4.3 cal-station. Starting from the left: mops burning vigorously; newspaper bundle not burning; canvas not burning; wrapping paper not burning; paper bags not burning; cardboard box with papers not burning; no burn in the trash can. Next three, all newspapers, burned out. Horizontal newspaper tray not burning. Next tray, rags, burning. Pine needles not burning. Horizontal newspaper tray at extreme right is not burning. There is trash burning out behind this station. I think it is the old fuel trays I threw out there

the other day.

H + 31 min. Approaching 3.1 cal-station. Nothing has burned at this station.

H + 33 min. Returning to compact auto group. Cars are still burning but fire doesn't seem to be spreading very much from one to the other. The Willys in the right rear is burning. I think that this is the only one burning. It is burning vigorously and its tires are on fire. There seems to be little or no spread to others.

H + 33-1/2 min. Approaching 12.2 cal-station. Second car seat from the right is burning vigorously now. The farthest to the right is burned but seems to be out. None of the other car seats is on fire. There is some smoke in the rear row. The car seat display box, second from the left, is smoking. All of the fences are burning now except the new fence. The fence with grass, the one to the right, is burning but has not burned out yet. The car seat third from the left looking away from ground zero is burning vigorously--the only one burning vigorously. There seems to be smoke coming only from the second car seat display, second from the left in the last row. Weather shelter looks all right. The burning car seat is the only big fire now at this station except for the cars. Wind is still blowing toward ground zero.

H + 34-1/2 min. Approaching 16.0 cal-station. No smoke now.

H + 35-1/2 min. Approaching 23.5 cal-station. No fire in the fuel tanks near this station. No sign of smoke in left-hand house of Project 8.11a.

H + 37 min. Approaching tree stand. There seem to be about 31 trees down but it may be a little bit more than that. No sign of fire anywhere in the tree stand. The anemometer looks pretty battered up. Anemometer cups on the top are still whirling but they have been bent over. Also the wind vane has been bent. There seem to be a few more trees down in the front of the stand than in the back, but not very many are broken. There seem to be between 30 and 40 trees down.

H + 39 min. Looking toward ground zero. There is very little smoke in the area. I see one fairly vigorous fire quite close to ground zero--one right on ground zero--a car is burning, I believe. There is something at about 30 cal/sq cm that is burning quite vigorously. I think it is the hospital, and it is still sending up a lot of smoke. Lots of yuccas burning over on the south slope of Frenchman Flat. Those are the only fires visible. There is some smoke still coming up from our 12.2 cal-station. No smoke visible at the other stations from this distance.

H + 41 min. Leaving area for Control Point.

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| Chief, Bureau of Ships, D/N, Washington 25, D. C. ATTN: Code 348 | 63 - 64 |
| Chief, Bureau of Yards and Docks, D/N, Washington 25, D. C. ATTN: P-312 | 65 |
| Chief, Bureau of Supplies and Accounts, D/N, Washington 25, D. C. | 66 |
| Chief, Bureau of Aeronautics, D/N, Washington 25, D. C. | 67 - 68 |
| Chief of Naval Research, Code 219, Rm 1807, Bldg. T-3, Washington 25, D. C. ATTN: RD Control Officer | 69 |

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| Commander-in-Chief, U. S. Pacific Fleet, Fleet Post Office, San Francisco, Calif. | 70 |
| Commander-in-Chief, U. S. Atlantic Fleet, U. S. Naval Base, Norfolk 11, Va. | 71 |
| Commandant, U. S. Marine Corps, Washington 25, D. C. ATTN: AO3H | 72 - 75 |
| President, U. S. Naval War College, Newport, R. I. | 76 |
| Superintendent, U. S. Naval Postgraduate School, Monterey, Calif. | 77 |
| Commanding Officer, U. S. Naval Schools Command, U. S. Naval Station, Treasure Island, San Francisco, Calif. | 78 |
| Commanding Officer, U. S. Fleet Training Center, Naval Base, Norfolk 11, Va. ATTN: Special Weapons School | 79 - 80 |
| Commanding Officer, U. S. Fleet Training Center, Naval Station, San Diego 36, Calif. ATTN: (SPWP School) | 81 - 82 |
| Commanding Officer, Air Development Squadron 5, VX-5, U. S. Naval Air Station, Moffett Field, Calif. | 83 |
| Commanding Officer, U. S. Naval Damage Control Training Center, Naval Base, Philadelphia 12, Pa. ATTN: ABC Defense Course | 84 |
| Commanding Officer, U. S. Naval Unit, Chemical Corps School, Army Chemical Training Center, Ft. McClellan, Ala. | 85 |
| Joint Landing Force Board, Marine Barracks, Camp Lejeune, N. C. | 86 |
| Commander, U. S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: EE | 87 |
| Commander, U. S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: R | 88 |
| Commander, U. S. Naval Ordnance Test Station, Inyokern, China Lake, Calif. | 89 |
| Officer-in-Charge, U. S. Naval Civil Engineering Research and Evaluation Laboratory, U. S. Naval Construction Battalion Center, Port Hueneme, Calif. ATTN: Code 753 | 90 - 91 |
| Commanding Officer, U. S. Naval Medical Research Institute, National Naval Medical Center, Bethesda 14, Md. | 92 |
| Director, U. S. Naval Research Laboratory, Washington 25, D. C. | 93 |
| Director, The Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y. | 94 |
| Commanding Officer and Director, U. S. Navy Electronics Laboratory, San Diego 52, Calif. ATTN: Code 4223 | 95 |
| Commanding Officer, U. S. Naval Radiological Defense Laboratory, San Francisco 24, Calif. ATTN: Technical Information Division | 96 - 99 |
| Commander, U. S. Naval Air Development Center, Johnsville, Pa. | 100 |
| Director, Office of Naval Research Branch Office, 1000 Geary Street, San Francisco, Calif. | 101 - 102 |
| Officer-in-Charge, U. S. Naval Clothing Factory, U. S. Naval Supply Activities, New York, 3rd Avenue and 29th Street, Brooklyn, N. Y. ATTN: R&D Division | 103 |

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| AIR FORCE ACTIVITIES | |
| Asst. for Atomic Energy, Headquarters, USAF, Washington 25, D. C. ATTN: DCS/O | 104 |
| Director of Operations, Headquarters, USAF, Washington 25, D. C. ATTN: Operations Analysis | 105 |
| Director of Plans, Headquarters, USAF, Washington 25, D. C. ATTN: War Plans Division | 106 |
| Directorate of Requirements, Headquarters, USAF, Washington 25, D. C. ATTN: AFDRQ-SA/M | 107 |
| Director of Research and Development, DCS/D, Headquarters, USAF, Washington 25, D. C. ATTN: Combat Components Div. | 108 |
| Director of Intelligence, Headquarters, USAF, Washington 25, D. C. ATTN: AFOIN 1B2 | 109 - 110 |
| The Surgeon General, Headquarters, USAF, Washington 25, D. C. ATTN: Bio. Def. Br., Pre. Med. Div. | 111 |
| Commander, Strategic Air Command, Offutt AFB, Omaha, Neb. ATTN: Operations Analysis | 112 |
| Commander, Tactical Air Command, Langley AFB, Va. ATTN: Documents Security Branch | 113 |
| Commander, Air Defense Command, Ent AFB, Colo. | 114 |
| Commander, Air Materiel Command, Wright-Patterson AFB, Dayton, O. ATTN: MCAIDS | 115 - 116 |
| Commander, Air Training Command, Scott AFB, Belleville, Ill. ATTN: DCS/O GTP | 117 |
| Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDDN | 118 - 120 |
| Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: AG/TRB | 121 |
| Commander, Air University, Maxwell AFB, Ala. | 122 - 123 |
| Commander, Flying Training Air Force, Waco, Tex. ATTN: Director of Observer Training | 124 - 131 |
| Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: 2GTS, DCS/O | 132 |
| Commander, Headquarters, Technical Training Air Force, Gulfport, Miss. ATTN: TA&D | 133 |
| Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex. | 134 - 135 |
| Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCOESP | 136 - 141 |
| Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Mass. ATTN: Atomic Warfare Directorate | 142 |
| Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Mass. ATTN: CRTSL-2 | 143 |
| Commander, Air Force Special Weapons Center, Kirtland AFB, N. Mex. ATTN: Library | 144 - 146 |
| Commandant, USAF Institute of Technology, Wright-Patterson AFB, Dayton, O. ATTN: Resident College | 147 |
| Commander, Lowry AFB, Denver, Colo. ATTN: Department of Armament Training | 148 |

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| Commander, 1009th Special Weapons Squadron, Headquarters, USAF, Washington 25, D. C. | 149 - 151 |
| The RAND Corporation, 1700 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division | 152 - 153 |

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

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| Asst. Secretary of Defense, Research and Development, D/D, Washington 25, D. C. | 154 |
| U. S. National Military Representative, Headquarters, SHAPE, APO 55, c/o PM, New York, N. Y. ATTN: Col. J. P. Healy | 155 |
| Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D. C. | 156 |
| Chairman, Armed Services Explosives Board, D/D, Rm 2403, Barton Hall, Washington 25, D. C. | 157 |
| Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary | 158 |
| Commanding General, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex. | 159 - 164 |
| Chief, Armed Forces Special Weapons Project, PO Box 2610, Washington 13, D. C. | 165 - 173 |
| Office of The Technical Director, Directorate of Effects Tests, Field Command, AFSWP, PO Box 577, Menlo Park, Calif. ATTN: Dr. E. B. Doll | 174 |

ATOMIC ENERGY COMMISSION ACTIVITIES

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| U. S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D. C. ATTN: Mrs. J. M. O'Leary (For DMA) | 175 - 177 |
| Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman | 178 - 180 |
| Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: Martin Lucero | 181 - 182 |
| University of California Radiation Laboratory, PO Box 808, Livermore, Calif. ATTN: Margaret Folden | 183 - 184 |
| Special Projects Branch, Technical Information Service, Oak Ridge, Tenn. | 185 |
| Technical Information Service, Oak Ridge, Tenn. (Surplus) | 186 - 274 |

ADDITIONAL DISTRIBUTION

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| Director, Forest Products Laboratory, North Walnut St., Madison 5, Wis. ATTN: Mr. H. D. Bruce | 275 |
| California Forest and Range Experiment Station, PO Box 245, Berkeley 1, Calif. ATTN: Mr. Wallace L. Fons | 276 |
| University of Pennsylvania, Department of Physiology, Philadelphia, Pa. ATTN: Dr. James D. Hardy | 277 |

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| Director, Naval Research Laboratory, Washington 25, D. C.<br>ATTN: Dr. E. O. Hulburt | 278 |
| Chief, Division of Fire Research Forest Service, U. S.<br>Department of Agriculture, Washington 25, D. C.<br>ATTN: Mr. A. A. Brown | 279 |
| Department of Chemical Engineering, Massachusetts<br>Institute of Technology, Cambridge, Mass.<br>ATTN: Prof. H. C. Hottel | 280 |



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